Strengthening Sorghum Research Collaboration in Asia

International Crops Research Institute for the Semi-Arid Tropics

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Abstract

The Asian Sorghum Scientists' Meeting was attended by 28 researchers from eight countries in the Cereals and Legumes Asia Network — Australia, China, India, Indonesia, Iran, Myanmar, Pakistan, and Thailand — and from ICRISAT The meeting reviewed the current status of collaborative sorghum research in Asia, identified new research priorities, and laid out plans for new initiatives in specific areas. These include marker-assisted selection to improve the stay-green trait, development of alternative cytoplasmic male-sterility systems, development of improved forage sorghums, and the creation of a database on available cultivars as a means to promote technology spillovers across countries. This publication contains the presentations made at the meeting, and a summary of the recommendations. It thus provides an overview of the current status of sorghum research in Asia, future research priorities, and progress that may be expected.

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Report of the Asian Sorghum Scientists' Meeting

18-21 Nov 1997
Suphan Buri, Thailand

Edited by

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Inaugural Session

Welcome Address

Narongsak Senanarong[1]

On behalf of the Field Crops Research Institute and its staff, I would like to express our warm welcome to all participants at the Asian Sorghum Scientists' Meeting. I hope you had a comfortable journey to Bangkok and that you will have a pleasant stay with us. Thailand has been a CLAN member since the network was established more than 5 years ago. We have benefited considerably in terms of germplasm exchange, workshops, sharing of information among scientists, and training. We are delighted to organize this meeting, especially since this is the first sorghum meeting in Asia outside of ICRISAT-Patancheru, and Thailand has been selected to host it. The meeting will be held mainly at the Suphan Buri Field Crops Research Center (SBFCRC), which is responsible for sorghum research. This 4-day meeting provides a great opportunity for our scientists to interact with you. As you can see, we have a busy schedule during the meeting: information exchange, discussions, planning activities for the future, and field trips in SBFCRC and to farmers' fields around Suphan Buri. It would also be appropriate to discuss in what form and in which ways sorghum research collaboration should function. I am confident the meeting will yield fruitful deliberations and meaningful outcomes.

Ladies and gentlemen, on behalf of the Field Crops Research Institute, and on my own behalf, once again, we welcome all of you to the meeting and hope you enjoy your stay as well as our cultural and traditional attractions, with a taste of Thai hospitality.

Thank you.

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Opening Address

Sanit Samosorn[1]

It is a great honor be invited to inaugurate the Asian Sorghum Scientists' Meeting this morning. On behalf of the Department of Agriculture, I wish to express my appreciation for the presence of sorghum researchers from Australia, China, India, Indonesia, Iran, Myanmar, Pakistan, Thailand, and ICRISAT at the opening ceremony of this meeting. Sorghum is an important cereal crop in Asia. It is grown as a grain crop for both human consumption and feed grain. It also offers great potential for supplementing fodder resources. Moreover, alternative uses such as alcohol, glucose, and starch are becoming increasingly important. In Thailand sorghum has been grown for several decades. In the early period, many lines were introduced from the USA and evaluated under farmers' conditions. Hegari and other introduced varieties were released and recommended. As a result, both area and production of sorghum in Thailand have increased. On average, the total area is about 160 000 ha and production is 250 000 t of grain each year. The grain is normally used for animal feed and export.

Sorghum production in Asia faces both abiotic and biotic constraints that need to be solved not only by individual countries, but also by a group of scientists or institutions from different countries, linked together through collaborative research partnerships. Setting up working groups to solve specific problems is recognized as the best strategy at present, since it encourages interaction, effective use of resources, and sharing of technologies among scientists from CLAN member countries.

The objectives of this meeting are to:

- Review research developments and changes in sorghum research needs in the region since the previous Asian Sorghum Researchers' Consultative Meeting at ICRISAT-Patancheru in 1993
- Identify the desired mode and nature of collaborative sorghum research for the future
- Outline objectives and plans for collaborative research in agreed areas, and propose ways to review and assess the effectiveness of these activities.

It is extremely important to share and pool knowledge and experience to accelerate development in the future. I do believe this meeting will emphasize the constraints of immediate concern and examine the feasibility of incorporating new activities for the future. I hope this meeting will be conducted with mutual friendship, understanding, and goodwill that could lead to remarkable successes, and that cooperation among Asian sorghum researchers will be further intensified after this meeting. I trust that with the vast experience and knowledge of the participants, this 4-day meeting of Asian sorghum scientists will be able to come up with effective and practical solutions and further strengthen cooperation within the network. Before concluding, I would

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like to thank ICRISAT, the Field Crops Research Institute, and the Asian Development Bank, the cosponsors for this meeting. Without their support, it would not have been possible to hold this meeting.

On this auspicious occasion, I declare the Asian Sorghum Scientists' Meeting open.

Thank you.

Changes in Research Organization at ICRISAT

J W Stenhouse[1]

Background

ICRISAT has faced severe reductions in funding since 1990. These amount to approximately 35% in real terms and even more when the effects of inflation are taken into consideration. In addition, there has been a marked shift in recent years in the external environment in which ICRISAT operates. In particular, the increased strength of the National Agricultural Research Systems (NARS), and the interest of NARS and donors to drive the agendas of ICRISAT and its sister centers, have been significant.

Because of funding reductions and the changed external environment, ICRISAT has been undergoing a series of changes in its organizational structure. The process was initiated in 1994, and continues. The recommendations of an external panel review of ICRISAT's research and management carried out in late 1996 have been especially important in shaping recent changes in structure and research direction. This paper summarizes the changes that have taken place and are continuing to take place in ICRISAT's research agenda and organizational structure.

Changes in Organizational Structure

Project mode. A fundamental change that was introduced during ICRISAT's reorganization was a shift to research funding through projects. Previously, the Institute did organize its research into projects, but not for the purposes of funding. Up to 1995, over 250 separate projects operated. During 1994 and 1995, a major research prioritization exercise was undertaken to determine which activities should be funded. The selected research activities were organized into 22 projects, of which five concerned sorghum. Funding of research was done through these projects from the beginning of 1996.

During 1996, further funding cuts necessitated a consolidation of the 22 research projects into 12 new, larger projects. The five sorghum projects in 1996 became one project in 1997. At the same time, there were substantial cuts in research activities. All these projects were global in their orientation, incorporating activities across ICRISAT's locations in Asia and Africa, with the aim of maximizing comparative advantages and eliminating duplication of effort.

Program structure. ICRISAT is now moving to a program structure in which the previous 12 projects will be replaced by three programs (Genetic Resources and Enhancement Program, Natural Resource Management Program, and Socio-Economics and Policy Program). The motivation for this change comes largely from the recommenda-

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tions of the external review conducted in 1996. This recommended major shifts in the research agenda, a simpler organizational structure, and reduced numbers of staff involved in administration and research management. The reorganization process is still under way and all the details are not yet finalized. However, this new program structure will be implemented in 1998.

Changes in Research Agenda

The external review in 1996 emphasized that, as custodian of large germplasm collections of its mandate crops, ICRISAT has a comparative advantage for research involving germplasm. The review therefore recommended a new focus on germplasm-related research. It proposed that strategic research in germplasm enhancement activities to bridge the gap between germplasm collections and utilization programs should be based in Asia and complemented by applied breeding programs in Africa. Greater emphasis should be placed on emerging biotechnology and information technology methods and their application to genetic resources.

The review also recommended that ICRISAT move the focus of its natural resource management research to Africa, and that emphasis in Asia should be limited to strategic research of global significance. It proposed that strategic natural resource management research should be carried out within the context of specific production systems.

The recommendations of the review have been accepted and have been partially implemented in 1997. These recommendations will continue to guide us as we move towards the three-program structure.

Consequences of the Changes

As a result of reduced funding and changes in research focus, ICRISAT's research portfolio is very much smaller than before. Staff numbers and operational funding for research have been cut to nearly half their previous levels. Applied breeding for Asia and crop protection research have been substantially reduced. There is a corresponding increase in emphasis on prebreeding activities that aim to produce intermediate products and information that will be of use in applied breeding programs carried out by others. Some of the intermediate breeding products that we envisage are gene pools, improved male-sterile lines, and improved resistance sources that can be base materials for NARS breeding programs.

There are corresponding changes in the way ICRISAT will operate in future. There will be an increased emphasis on partnerships and collaboration, because there are many things that we will not be able to undertake alone. We anticipate greater reliance on special projects developed jointly with NARS partners and advanced research institutes to attract funds for priority research activities. We also wish to target greater involvement in development projects, particularly in Africa but also in Asia, if required, to ensure enhanced relevance and impact of research. For this, we envisage operating increasingly in a consultancy mode where we offer our expertise in the market.

Finally, we anticipate a greater role for ICRISAT in future as a source of information on all aspects of the germplasm and improvement of our mandate crops. Associated with this, we hope to play a greater role in linking the outputs of advanced research institutes with applications in applied programs in NARS.

Conclusions

The future ICRISAT will be smaller and leaner, with a much reduced core staff and research program. In view of this, we need to revisit the kinds of support that ICRISAT can provide and determine clearly where and what it can contribute, and how it can best act as a catalyst to assist NARS research efforts. We look forward to discussing, in the next few days, the needs of Asian NARS for support in sorghum research.

Thematic Presentations

Working Groups for Collaborative Sorghum Research in Asia

A Ramakrishna and C L L Gowda[1]

Introduction

Agricultural research is facing a severe funding crunch globally, but especially in developing countries. Research administrators and scientists are being asked to cut costs and maximize the efficiency of research output. Therefore, there is a need for collaborative research for effective utilization of scarce financial and human resources, to find solutions to important production constraints. A working group (WG) consists of scientists who share a common interest, and are committed to collectively addressing a high-priority regional problem, and sharing their research results with others. WGs coordinate and stimulate cooperative research by pooling expertise from both developing and developed countries, international research centers, and specialized research laboratories and institutions, to work together on a common platform as equal partners. WGs use existing staff and facilities, and avoid duplication of effort.

The membership of a WG may include scientists from national programs, international and regional institutions, and advanced research institutions. Each WG nominates a Technical Coordinator (TC), normally an expert on the subject, to liase, coordinate, and harmonize research. The TC is usually supported by a network or institution that provides the necessary administrative and logistic support. The WG members plan the research agenda, share research responsibilities and results, and meet once in 2-3 years to review progress and plan future research activities. Currently, six Working Groups operate under the Cereals and Legumes Asia Network (CLAN). They focus on: groundnut viruses in the Asia-Pacific region; bacterial wilt of groundnut; botrytis gray mold of chickpea; nitrogen fixation in legumes; aflatoxin management in groundnut; and drought tolerance in legumes.

Status of Working Groups for Sorghum Collaborative Research in Asia

Sorghum is an important cereal worldwide but its production has not kept pace with demand. A Consultative Group Meeting of Asian Sorghum Scientists was held during 16-19 Sep 1991 at ICRISAT-Patancheru to assess the need for regional collaboration and to discuss common production constraints, research priorities, and dissemination of technologies to farmers. The group resolved to establish a Sorghum Research and Development Network for Asia to enable rapid progress in technology generation, and

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its adaptation and adoption by farmers. The group also recommended that ICRISAT should initiate and coordinate the activities of this network. The overall goal of the network was to elevate the status of sorghum from that of a subsistence crop to a high-value crop. Subsequent developments and the formation of a unified Cereals and Legumes Asia Network (CLAN) resulted in changes in the organizational set up.

To carry forward the recommendations of the 1991 meeting, the Asian Sorghum Researchers' Consultative Meeting was organized during 27-29 Sep 1993, at ICRISAT-Patancheru. The meeting recommended that future collaborative research on sorghum be integrated into CLAN to strengthen collaborative research and technology and information exchange both within and outside the network. Considering the success of the Working Group approach in other CLAN priority crops, the participants agreed to form working groups to address specific problem areas as an appropriate way to conduct sorghum research and development in Asia. As a first step in the development of working groups, the production constraints in individual countries were reviewed. There were no major changes in regional priority between 1991 and 1993. As a result of this analysis, four working groups — on drought, shoot pests, grain mold, and forage sorghums — were identified. Plans were made for collaborative research activities in each group, and responsibilities and target areas were identified for each country. However, progress has been very slow compared to other WGs and only a few activities were initiated.

- Sorghum shoot pests — nurseries containing resistant germplasm and breeding lines were sent to Myanmar, Pakistan, and Thailand for evaluation.
- Drought tolerance — a questionnaire was sent to interested sorghum scientists. Responses were summarized and circulated to respondents for comments. A nursery of drought-tolerant lines was sent to interested scientists for evaluation.
- Sorghum grain mold — a sorghum grain mold nursery was distributed to interested scientists.
- Forage sorghums — a forage sorghum (single and multicut) nursery was distributed to interested scientists.

Conclusions

Compared to other CLAN Working Groups, the four sorghum WGs have not shown the progress expected. We need to introspect, to understand the reasons for the slow progress, and suggest ways to improve and strengthen collaboration. We need to rethink the whole issue, and suggest better ways to improve linkages among scientists, and to further the cause of sorghum research and development in Asia.

Diversification of Sorghum Male-Sterile Lines at ICRISAT

B V S Reddy and Prakasha Rao[1]

Introduction

World sorghum production was approximately 54 million t from 44 million ha in 1995. Developing countries account for roughly 90% of the area and 70% of production. In Asia about 15 million t are produced annually from about 14.1 million ha (FAO 1996). Sorghum is grown in a wide range of environments, and encounters various biotic and abiotic stresses such as drought, low temperatures, Al^{+3} toxicity, *Striga,* stem borer, shoot fly, head bug, midge, grain mold, downy mildew, anthracnose, leaf blight, and rust. Breeding for resistance to these stresses stabilizes yield levels and is a relatively inexpensive way to protect the crop from the major yield constraints. With the discovery of cytoplasmic-nuclear male-sterility (Stephens and Holland 1954), hybrids became popular with farmers in USA, China, India, Australia, and Thailand. In recent years, there has been increasing international collaboration on sorghum research. ICRISAT aims to develop high-yielding and diversified, broad-based genetic materials (gene pools, varieties, and seed parents) with resistance to various stresses, and thus better serve the needs of collaborators and partners. This paper summarizes ICRISAT's efforts in diversifying and improving male-sterile lines through a trait-based breeding approach.

Materials and Methods

The high-yielding male-sterile lines available with ICRISAT and others are primarily caudatum, based in milo-cytoplasm sources. Selected high-yielding maintainer lines were crossed to the sources for resistance to diseases, insect pests, and *Striga,* and sources of stay-green and durra and bold-grain lines in single and three-way crosses. Selection for agronomic desirability and for high-heritability traits such as plant height and days to flowering was done in the F_2 generation. Selection coupled with test crossing and conversion of the improved maintainer lines was followed in order to develop bold grain, stay-green, and early male-sterile lines. To breed resistant male-sterile lines, appropriate screening techniques (Rao 1985, Butler and Bandyopadhyay 1990, Sharma et. al. 1992, Singh, 1993, Singh et. al. 1997) were employed from the F_3 generation onwards, coupled with pedigree selection and simultaneous conversion methods. The high-yielding milo cytoplasm B and R-lines were converted into male steriles through regular backcrossing on an A_2 cytoplasm base. In backcrossing and

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conversion, plant to plant or paired crossing with selection of desirable plants in the pollinating maintainer lines was followed. Appropriate populations and plot sizes were maintained in various generations depending on the complexity of the trait. Families were selected on the basis of resistance, following which individual plants from these families were selected for agronomic desirability and high yield.

Results and Discussion

A program for the diversification of male-sterile lines was initiated at ICRISAT-Patancheru in 1990/91. The program yielded 613 lines that are nearing the stage of complete conversion into male-sterile lines. The materials from USA (e.g., Tx 623A) and India (e.g., 296A) are milo-cytoplasm based, widely available, and adapted to tropical environments. Although these lines have high performance and high general combining ability they lack resistance to various stresses.

Based on available data on male-sterile lines developed at ICRISAT (Table 1), the following generalizations can be made.

- Significant progress has been made in improving resistance in various male-sterile lines.
- Since selection was practised for resistance and grain yield, the number of final selections generally reflects the efficiency of each selection program. Resistance to midge, anthracnose, leaf blight, downy mildew, *Striga,* and shoot fly (postrainy season) was successfully improved. Success was limited for grain mold and stem borer resistance.
- Considerable variability has been retained in the selections for plant height, days to flowering, and agronomic desirability. This variability will help further selection and development of male-sterile lines adapted to various agroclimatic conditions.
- In general, the midge-resistant and downy mildew resistant lines were highly productive, with grain yields on par with 296B. Further cycles of breeding in some resistant male-sterile lines are needed to improve grain yield to the desired levels.
- An examination of the pedigrees of the selected lines showed that several sources contributed to the final selections within each trait. This indicated that the needed diversity has been achieved.

Summary

The male-sterile line diversification program initiated in 1990/91 resulted in the development of male-sterile lines resistant to various stresses. They were also diversified for various agronomic traits such as stay-green, earliness, and bold grain (durra race). High-yielding lines with non-milo cytoplasm male sterility have also been bred. Some of these lines give yields lower than the high-yielding control (296 A). Future emphasis will be placed on classification and characterization of newly developed male-sterile lines, and on enhancing yield in resistant derivatives.

Table 1. Sorghum seed parents evaluated and selected for resistance at ICRISAT-Patancheru, 1995.

	Trial statistics				B-lines tested		Controls		B-lines selected	
		Resistance levels								
Stress	No. of entries	Mean	Range	SE±[1]	No.	Resistance level range	Entry[2]	Resistance level	No.	Truncation value
Grain mold										
Head mold[3] (HMR)	90	6.0	3.0-9.0	0.35 (178)	75	3.3-8.3 296[S]	IS 15119[R] 8.4	3.3	31	≤5.5
Grain mold[4] (TGMR)	90	6.2	2.8-9.0	0.31 (178)	75	3.3-8.1 296B[S]	IS 15119[R] 8.6	4.0	31	<6.0
Anthracnose[5]	50	5.5	3.0-9.0	0.30 (98)	47	3.0-7.0	A 2267-2[R] FSRP Local[S]	4.0 9.0	29	≤5.0
Leaf blight and rust[6]										
Leaf blight	80	4.8	2.7-9.0	0.50 (158)	38	3.3-6.3	A 2267-2[R] FSRP Local[S]	2.8 9.0	15	≤4.0
Rust	80	2.5	1.9-6.7	0.33 (158)	30	1.9-6.7	A 2267-2[R] FSRP Local[S]	2.0 3.0	16	≤2.0
Shoot fly[7]										
B-lines	90	69.9	35.4-97.3	5.70 (178)	40	35.4-86.4	IS 18551[R] CSH 1[S]	60.0 91.2	23	≤66
F_2s	141	90.5	43.8-100	4.25 (140)	127	79.0-100	IS 18551[R] CSH 1[S]	56.9	20	≤86
Stem borer[7]										
Rainy season	100	65.5	4.4-100	9.59 (297)	20	4.4-84.5	IS 2205[R] ICSV 1[S]	25.2 68.5	13	≤45
Midge[8]										
B-lines	90	3.1	2.0-6.0	0.41 (89)	65	2.0-4.5	ICSV 197/ ICSV 745[R], CSH 1[S]	2.7 5.9	54	≤3.0
Striga[9]										
At Patancheru	61	1.1	0.0-7.0	1.13 (120)	41	0.0-2.0	SAR 1[R] CSH 1[S]	0.0 3.0	27	0.0
At Akola	61	2.0	0.0-10.7	1.04 (120)	41	0.0-3.3	SAR 1[R] CSH 1[S]	0.0	20	≤1.0

1. Applies also to B-line and controls; values in parentheses are error degrees of freedom.
2. R = Resistant control , S = Susceptible control.
3. HMR = Head Mold Rating on a 1-9 scale, where 1 = free from mold, 9 = >50% of the grains with mold.
4. TGMR = Threshed Grain Mold Rating on a 1-9 scale, where 1 = free from mold, 9 = >50% of grain surface area molded.
5. Anthracnose score on a 1-9 scale, where 1 = no lesions, 9 = >75% leaf area covered with anthracnose lesions.
6. Leaf blight and rust scored on a 1-9 scale, where 1 = leaf lamina free from disease, 9 = >80% leaf area affected by disease.
7. Shoot fly and stem borer resistance assessed based on deadheart percentage.
8. Midge visual scoring on a 1-9 scale, where 1 = <10% chaffy florets, 9 =>80% chaffy florets.
9. Maximum mean *Striga* plant count per plot.

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Drought Tolerance in Sorghum: Current Status

V Mahalakshmi[1]

Sorghum productivity is limited by drought stress during crop growth, the most damaging being terminal stress from flowering through grain filling. The non-senescent or 'stay-green' trait in sorghum has received considerable interest as a possible mechanism of drought, lodging, and charcoal rot resistance (Mughogho and Pande 1984), and as a means of improving fodder yield and quality (McBee et al. 1983). When water is limiting during the grain-filling period, plants with the stay-green trait maintain green leaf and stem for longer periods than do plants without this trait.

Knowledge on the inheritance of stay-green is a prerequisite for the successful use of this trait as a selection criterion. Non-senescence in sorghum, measured as green leaf area retention, was reported to be regulated by both dominant and recessive epistatic interactions (Tenkouano et al. 1993, Walulu et al. 1994). Two different types of non-senescence functions can be distinguished, involving either a delayed onset of leaf senescence or a slower rate of senescence. The reported dominance was mainly due to dominance of reduced rate of leaf senescence, while the onset of senescence was additive. The dependence of leaf senescence on soil water can result in genotype x environment interaction (van Oosterom et al. 1996). Both stable and unstable expression of stay-green across environments have been reported (Mughogho and Pande 1984) and the level of dominant gene-action depends on the environment (Walulu et al. 1994). Therefore, the non-senescent trait is difficult to select using traditional plant breeding techniques. Molecular markers provide a new means of selecting for this trait, and marker-assisted selection will increase the efficiency and effectiveness with which improved varieties containing this trait can be developed.

An essential part of developing molecular markers for stay-green is the phenotypic description of recombinant inbred lines (RIL) differing in the expression of this trait. Two different sets of RILs involving a senescent and a non-senescent parent (one set from the Queensland Department of Primary Industries, Australia, and the other from Purdue University, USA) were evaluated over 2 years for phenotypic description of the lines, including their ability to retain green leaf area and yield under drought conditions. Markers will soon be available for the stay-green trait. Once these markers are available, it should be possible to routinely use them in a breeding program targeting genotypes for drought-prone regions.

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Sorghum Grain Mold: Current Status

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Introduction

Grain mold is an important biotic constraints of sorghum, and seriously compromises the grain yield and quality gains obtainable from improved cultivars. This disease gained worldwide significance after the widespread introduction and cultivation of short-duration sorghum cultivars that replaced longer-duration landraces and local cultivars. The newer cultivars matured and set seeds under wet and humid conditions that were favorable for the development of grain mold fungi. Damage caused by grain mold includes losses in seed yield, quality, market value, storage quality, viability, and food and feed processing quality of seed. In addition, several mold-causal fungi produce mycotoxins in grain. Mycotoxins in feed slow the growth rate, predispose animals to other infections, and are teratogenic and carcinogenic.

Due to its importance, grain mold research has been an integral part of sorghum research in several national programs and at ICRISAT In addition, sorghum researchers in CLAN member countries established a working group on grain mold in 1993. ICRISAT's research on grain mold has evolved over time and can be described in three phases: 1973 to 1990, 1991 to 1996, and 1997 and beyond.

Research Progress up to 1990

During the first phase (1973 to 1990), the major mold-causal fungi were identified — *Fusarium moniliforme, F. pallidoroseum, Curvularia lunata,* and *Phoma sorghina.* These mold fungi were shown to infect and colonize grain from flowering until grain maturity. The deleterious nature of moldy grains in food processing was quantified in collaborative studies by biochemists and pathologists. Initially, resistance-screening activities were conducted in the field using sprinkler irrigation and inoculation and bagging of panicles.

Several lines with putative resistance to grain mold were identified (IS 18758 and IS 14332). These lines were used in a breeding program to develop high-yielding, mold-resistant sorghum cultivars. However, high levels of mold resistance in high-yield backgrounds could not be combined. Later, the field screening technique was simplified to evaluate mold resistance in germplasm and breeding lines. The modified technique involved wetting panicles of plants from the flowering stage up to two weeks after grain maturity. Panicle inoculation was not necessary since aerobiological studies showed that abundant spores of mold fungi were naturally available to infect developing grains. Studies on headbug grain mold interaction showed that headbug damage increases mold damage, even in mold-resistant genotypes. Using the field

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screening technique, more than 13 000 germplasm lines were screened and 156 lines identified as mold resistant. All mold-resistant lines had colored grain with the exception of IS 25017 (white grain). Most of the colored-grain lines had a testa layer, but five colored-grain lines were devoid of testa and were red in color. Nearly 50 of these resistant sources were evaluated in the International Sorghum Grain Mold Nursery for 7 years. Most of these test lines showed stable resistance across locations and years. Tannins, flavan-4-ols, and grain hardness were shown to be the three major factors associated with resistance. Tannin and flavan-4-ols were associated with resistance in genotypes with a colored pericarp and pigmented testa. Flavan-4-ol was the primary determinant of resistance in the colored-grain genotypes that lacked a testa layer. In the white-grain genotypes, tannins and flavan-4-ols were absent, and grain hardness was the major factor associated with resistance. Several of these lines were used in another mold resistance breeding program to determine whether resistance from the colored grain could be transferred to elite, white-grain backgrounds. While it was possible to obtain white-grain, mold-resistant lines, the yield levels of these new breeding lines were not high.

Research Progress, 1991-96

One drawback of field screening is that it can be conducted only once in a year during the rainy season. Therefore, an in vitro screening technique was developed in which mature threshed grains were inoculated with a spore suspension of individual mold fungi, then incubated in a moist chamber for 5 days, and evaluated for mold incidence and severity. Using the in vitro screening technique, mold evaluations can be separately done for individual mold fungi at any time of the year. This is in contrast to field screening, where it is difficult to partition the severity of individual mold fungi. In this phase, a major effort was directed towards identification of sources with high levels of mold resistance in white-grain backgrounds. A large number of lines from an ICRISAT sorghum conversion program and photoperiod-sensitive lines were screened using field screening and/or *in* vitro methods. Several photoperiod-sensitive sorghum lines with high levels of resistance and converted lines with moderate levels of resistance were identified. The likely mechanism associated with resistance in the photoperiod-sensitive lines is the presence of antifungal proteins. The mold-resistant converted sorghum lines had short grain-filling periods. These lines were used in another mold resistance breeding program. Also, a separate seed parent breeding program was initiated to develop high-yield potential, mold-resistant, red-grain (without testa) A, B, and R lines using colored-grain mold resistance sources identified during the first phase. Because of their poor agronomic characteristics, the photoperiod-sensitive lines were difficult to use in the breeding program. However, it was possible to develop the desired red-grain F_1 hybrid seed parents and varieties with mold resistance. In mold-endemic areas these cultivars have potential for use as feed, locally or for export.

Research Progress in 1997, Future Strategies

Two major research gaps that still remain are: inadequate levels of resistance in high-yielding white-grain sorghum and lack of epidemiological information on the relationship between climatic factors and grain mold incidence and severity. Research on these two areas began in 1997. Bioassay methods to determine toxicity of antifungal proteins have been developed using purified antifungal protein extracts from mold-resistant genotypes. Relative humidity above 98% was essential for sporulation of *F. moniliforme,* but the humidity requirement and duration varied for different mold fungi. In field experiments, it was found that panicle wetness at or after maturity is favorable for mold development.

Conventional breeding methods have not been successful in developing white-grain, mold-resistant lines in high-yield backgrounds. This is because grain mold is caused by multiple pathogens and variable fungal species. Also, the environment heavily influences the expression of resistance. Several quantitative traits influencing resistance have been identified. Therefore, it is desirable that a combination of conventional and biotechnology approaches is followed to understand the mechanisms of resistance and then use molecular tools to transfer resistance. Antifungal proteins defend plants against plant pathogens. Among the antifungal proteins, chitinases, ß-glucanases, sormatins, and ribosome-inhibiting proteins are noteworthy in inhibiting fungal growth. Chitinases have been found in mold-resistant sorghums and their over-expression or production of more effective forms in grains may be beneficial. Genes encoding chitinases have been identified. Transformation of sorghum with engineered promoters and coding regions for chitinases may assist in the development of resistant varieties. Initial work on antifungal proteins, in collaboration with Texas A&M University, USA, will center around the insertion and expression of chitinase and glucanase genes from *Trichoderma* species into *E. coli,* extraction of these proteins, and testing of fungitoxicity against the predominant mold fungi. Later, transformation systems with several candidate genes will be developed. A second approach will focus on the development of molecular markers for several quantitative trait loci (QTL) that can increase the efficiency of conventional breeding methods. Research on this aspect has begun at Texas A&M University, but there is scope for using different and multiple parents to develop mapping populations for the marker study. Several candidate parents are being identified and there is excellent scope for partnerships between the national programs, advanced research institutes, and ICRISAT.

Epidemiological information on the role of climatic factors in mold development would assist in two ways. Firstly, to refine in vitro screening techniques, particularly to assess mold resistance under variable disease pressure. Secondly, to develop risk assessment models that can aid the breeding process and the deployment of cultivars of desired maturity that can escape high mold pressure on one hand and terminal drought on the other. Future epidemiology research needs are to determine the need of free water for infection; study the effect of temperature, relative humidity, and wetness on sporulation; and determine the effect of wetness at different post-flowering stages on mold development. Using the data, it should be possible to develop models to predict mold development and to characterize sorghum-growing regions for mold risk. There is scope for collaborative research in this area, particularly for model development and risk assessment.

Host-Plant Resistance to Shoot Fly and Spotted Stem Borer in Sorghum

H C Sharma[1]

Introduction

Nearly 150 insect species have been reported as pests on sorghum, of which shoot fly (*Atherigona soccata),* stem borer (*ChibparteUus),* army worm *(Mythimna separata),* aphids *(Rhopalosiphum maidis, Melanaphis sacchari),* shoot bug *(Peregrinus maidis),* sorghum midge (*Stenodiplosis sorghicola),* head bug (*Calocoris angustatus),* and head caterpillars *(Helicoverpa armigera, Cryptoblabes gnidiella, Eumlemma silicula,* etc.) are the major pests in Asia.

Shoot Fly *(Atherigona soccata)*

Sources of resistance

The shoot fly lays eggs on 7-20 day old plants on the undersurface of leaves. The larvae move to the growing point and cut it. As a result, the central leaf dries up, resulting in a deadheart. Screening for resistance to shoot fly can be carried out using interlard or cage screening techniques (Sharma et al. 1992). Several workers have screened sorghum germplasm for resistance to shoot fly (Jotwani 1978, Singh and Rana 1986, Taneja and Leuschner 1985, Sharma et al. 1992). Cultivars M 35-1 (IS 1054), IS 1057, IS 2123, IS 2146, IS 4664, IS 2205, IS 5604, and IS 18551 have been widely tested, and possess moderate levels of resistance. Improved varieties CSV 5, CSV 6, CSV 7R, Swati (SPV 504), and CSV 8R have been developed using landraces, and possess moderate levels of resistance. Improved lines such as ICSV 700, ICSV 705, ICSV 717, PS 19345, PS 19349, PS 21303, PS 28060-3, and PS 35805 have moderate levels of resistance to shoot fly, and higher yield potential than landraces.

Resistance mechanisms

Nonpreference for oviposition. This is the primary mechanism of resistance to shoot fly (Taneja and Leuschner 1985, Sharma and Nwanze 1997). Significantly higher oviposition has been recorded on the susceptible cultivar CSH I (66% plants with eggs) compared with resistant genotypes IS 1034, IS 2146, IS 2265, IS 2309, IS 3962, IS 4664, IS 5566, IS 5604, IS 18369, and IS 18551 (<40% plants with eggs). However, more eggs have been recorded on shoot fly-resistant cultivars IS 1082, IS 2122, IS

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2195, IS 4664, IS 5484, and IS 5566 under no-choice than under multiple-choice conditions.

Antibiosis. Survival and development of the shoot fly are adversely affected when the insect is reared on shoot fly-resistant genotypes. Growth and development of the insect are retarded, and the larval and pupal periods are extended by 8-15 days on resistant genotypes. Survival, longevity, and fecundity of females are also adversely affected when the fly is reared on resistant genotypes (Sharma and Nwanze 1997).

Tolerance. Some sorghum genotypes exhibit an inherent ability to produce side-tillers after the main shoot is killed by shoot fly. These genotypes can produce reasonable yields if the plant is not attacked again (Taneja and Leuschner 1985). Tillers of resistant cultivars are less preferred for egg-laying. Resistant cultivars have a higher rate of tiller survival than do susceptible cultivars.

Factors associated with resistance

Seedling vigor. Seedling vigor is negatively associated with deadheart formation. Shoot fly-resistant lines have rapid plant growth (Taneja and Leuschner 1985), greater seedling vigor, longer stems and internodes, and a short peduncle (Sharma and Nwanze 1997).

Glossiness. The glossy leaf trait (pale green, shiny leaves) in sorghum is associated with shoot fly resistance (Taneja and Leuschner 1985). Intensity of glossiness of the leaves at the seedling stage is positively associated with resistance.

Leaf surface wetness. Cultivars with a high transpiration rate are preferred for oviposition. Shoot fly-resistant lines have low leaf surface wetness, and are characterized by a smooth amorphous wax layer and sparse wax crystals (Sharma and Nwanze 1997).

Trichomes. Trichomes on the undersurface of leaves are associated with shoot fly resistance (Taneja and Leuschner 1985). Shoot fly-resistant germplasm lines have trichomes on the undersurface of leaves (except IS 5622, which has trichomes only on the upper surface). Trichomes are absent in shoot fly-susceptible lines.

Biochemical factors. Such factors as the presence of irregularly shaped silica bodies in plant tissue, lignification, silica deposition, nitrogen, reducing sugars, total sugars, moisture, chlorophyll, lysine, amino acids, phenol, and phosphorus have been found to be associated with resistance to shoot fly (Sharma and Nwanze 1997).

Stem Borer *(Chilo partellus)*

Sources of resistance

Stem borer moths lay eggs on the undersurface of leaves. The young larvae feed inside the leaf whorls of 15-40 day old plants, causing leaf scarification. Third-instar larvae move to the base of the plant, bore inside the stem, and kill the growing point. As a result, the two central leaves dry up, producing a deadheart. The larvae also tunnel the stem, and often lead to completely or partially chaffy panicles or peduncle damage. Screening for stem borer resistance can be carried out at hot-spot locations or through artificial screening using laboratory-reared insects. Sources of resistance have been identified by several workers (Jotwani 1978, Singh and Rana 1989, Sharma et al. 1992). IS 1055 (BP 53), IS 1044, IS 2123, IS 2195, IS 2205, IS 2146, IS 5469, and IS 18551 show moderate levels of resistance to the spotted stem borer. The improved lines ICSV 700, ICSV 714, PB 15837-1, PB 15925, PB 15520-2-2-2, and PB 14390-4 have moderate levels of resistance, and better plant type and yield potential than the original resistance sources.

Resistance mechanisms

Nonpreference for oviposition. Ovipositional nonpreference is one component of resistance to *Chilo pattellus* (Sharma and Nwanze 1997). In cage tests, Saxena (1990) observed that oviposition was equally high on susceptible cultivars (IS 18363, IS 18463, and IS 2146) and moderately resistant cultivars (IS 4660 and IS 2205). However, oviposition was significantly lower on resistant cultivars (IS 18520 and IS 1044).

Antibiosis. The main mechanism of spotted stem borer resistance in sorghum is antibiosis. High mortality in the early larval stages, low larval establishment, time interval between larval hatching and boring into the stem, larval mass, and survival rate are associated with resistance (Jotwani 1978, Sharma and Nwanze 1997). Different combinations of factors are involved in conferring resistance to C. *partellus* in various genotypes, and information on these factors is vital while breeding for resistance to stem borers.

Tolerance. In studies conducted at ICRISAT-Patancheru, lines showing resistance to deadheart formation, i.e., <20% plants with deadhearts (IS 5604, IS 5469, IS 2123, IS 5566, IS 2146, and IS 2309), also exhibited good recovery resistance. Grain yield under infested and noninfested conditions can also be used as a measure of tolerance (Sharma and Nwanze 1997).

Factors associated with resistance

Plant morphological characters. Plant height, tassel percentage, stem thickness, number of leaves, leaf length, leaf width, leaf thickness, and leaf strength are negatively correlated with deadheart formation (Khurana and Verma 1985). Days to panicle initiation and shoot length are associated with resistance to stem borers. Genotypes with early panicle initiation (IS 12308 and IS 13100) escape deadheart formation due to inability of the larvae to reach the growing point. Faster internode elongation is also associated with borer resistance. Shoot length, moisture content, plant growth rate or seedling vigor, leaf glossiness, and ligular hairs are associated with resistance (Sharma and Nwanze 1997).

Biochemical factors. A number of biochemical factors such as amino acids, sugars, tannins, phenols, neutral detergent fiber, acid detergent fiber, lignins, and silica content are associated with resistance to the stem borer (Sharma and Nwanze 1997). The epicuticular wax layer in sorghum plants is conspicuous and hampers climbing by *Chilo* larvae (Bernays et al. 1983). Concentration of 32 C marker chemical in resistant genotypes (IS 2205) was less than half the concentration in susceptible genotypes (IS 1151, CSH 1). Larval mortality is higher when larvae are fed on a diet impregnated with a petroleum ether extract of borer-resistant lines. Methanolic extracts from the susceptible line IS 18363 caused greater feeding stimulation than did extracts from a less susceptible cultivar, IS 2205. IS 18363 has greater phenolic and sugar contents than IS 2205 (Torto et al. 1990).

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Status of Forage Sorghum Research in India

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Introduction

Sorghum has special significance in India because it is grown both for grain and to supplement fodder. It is popular as a forage crop because of its wide adaptation, quick growth, high yield, and good fodder quality. It is fed to animals as green chop, silage, or hay. The major emphasis of sorghum research in India has been on improvement for grain; forage has generally been considered to be secondary. But due to the increasing requirement for fodder (in turn due to increase in livestock population and greater demand for milk and milk products), efforts have been made in recent years to improve forage sorghum. This paper describes the trends in forage sorghum production, constraints, achievements in forage sorghum research, and future thrusts.

Area, Production, and Productivity

Sorghum is cultivated for forage production in most of the country's sorghum-growing areas but particularly in Punjab, Haryana, Delhi, Uttar Pradesh, Gujarat, and Rajasthan. There are no statistics available on the total area, production, and productivity of forage sorghum. But surveys conducted by the CCS Haryana Agricultural University show that forage sorghum area has increased during the last 5 years in most states in northern India, and in a few others, because of highly remunerative prices for fodder. The productivity of forage sorghum has increased from 20 t ha^{-1} to more than 35 t ha^{-1} of green fodder in single-cut varieties, and from 60 t ha^{-1} to over 75 t ha^{-1} of green fodder in multicut varieties. This has been possible mainly due to the adoption of improved varieties and better management technology.

Demand and Supply of Fodder

Livestock population is likely to increase to 666.2 million head by 2020 as against 448.7 million head in 1989. Therefore, demand for green and dry fodder is likely to increase considerably. In order to meet future demand, the production of fodder needs to be increased by breeding high- yielding forage cultivars with good fodder quality, and developing improved production technology. This need is particularly urgent because the area under forage sorghum is unlikely to increase since grain and commercial crops are more of a priority.

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Production Constraints

The major constraints in forage sorghum production are: (i) limited irrigation, leading to drought stress and high cost of inputs, (ii) non-availability of quality seed, (iii) poor soils with poor management, (iv) insect pests and diseases, (v) price variation and inadequate marketing facilities, (vi) limited conservation of surplus fodder, (vii) inadequate transfer of improved production technology, (viii) lack of widely adapted, high-yielding varieties with good fodder quality.

Current Research and Achievements

The improvement of forage sorghum focuses on development of cultivars with high fodder yield, good quality, high grain yield, suitability to production systems, and resistance to insect pests and diseases; and on developing improved production technology. Considerable achievements in forage sorghum have been made in India. More than 15 single-cut varieties of forage sorghum have been released at the national level. The most promising among these are HC 136, HC 171, HC 260, HC 308, PC 6, PC 9, RC 1, RC 2, and UP Chari 1 and 2. Varieties such as HC 171, HC 260, HC 308, and UP Chari 2 are resistant to foliar diseases. HC 171 is also resistant to stem borers. Recently four hybrids have been released — LX-250 in Punjab, AS 16 in Gujarat, and Hara Sona and PCH 106 in Haryana. The newly released multicut hybrids yield 80-85 t ha^{-1} of green fodder. Single-cut genotypes S 437, S 490, and CSV 15 and multicut hybrids HH1, GK 905, and NFSH 10659 tested in advanced trials performed exceedingly well at the national level. Most of these new genotypes are resistant to foliar diseases. Soluble sugars in stalk and root and low hydrocyanic acid (HCN) content have been found to be responsible for their quick regeneration, tillering, and growth. Forage sorghum production technology relating to sowing time, seed rate, spacing, fertilizer requirement, irrigation, management of weeds, HCN, insect pests and diseases, harvesting, mixed cropping, and crop rotations has been standardized to enhance forage sorghum production.

Collaboration with ICRISAT on a project titled 'Development and testing of multicut hybrids' has resulted in the identification of useful multicut genotypes and promising male-sterile lines with better regeneration and faster growth. Promising sorghum genetic stocks for various other traits (forage yield, agronomic and quality traits) have been identified and are being used in the breeding program.

Future Thrust Areas

There is little possibility of increasing the area under forage sorghum. Therefore, the only option is to increase its productivity per unit area and per unit time. The target is to evolve varieties/hybrids of forage sorghum with green forage yield potential of 100 t ha^{-1} with improved quality. To achieve these goals collaboration with national and international organizations is needed in the following areas:

- Germplasm resources and identification of promising genetic stocks
- Development of cultivars resistant to major foliar diseases and shoot pests
- Improvement of forage quality
- Breeding Sudangrass and sorghum restorers and forage type male-sterile lines with profuse tillering, better regeneration, and faster growth
- Development of multicut forage sorghum hybrids
- Development of dual-purpose forage sorghums
- Development of forage sorghum cultivars for drought/limited irrigation and suitable for various cropping patterns.

Sorghum Database Development to Enhance Technology Spillovers

U K Deb and M C S Bantilan[1]

Introduction

For the last 25 years, joint efforts by ICRISAT and national agricultural research systems (NARS) have generated many improved cultivars and management practices to increase sorghum productivity throughout the world. These technologies are usually targeted at a particular environment or location. However, many of these technologies have been adopted beyond the target environments. For example, ICSV 112 (SPV 475) was primarily intended for India, but was released in Mexico (UNAL 1-87), Nicaragua (Pinoleso), and Zimbabwe (SV 1). This variety yields 3.4 t ha^{-1} and matures in 115-120 days (ICRISAT 1990). Another ICRISAT sorghum germplasm line, IS 9830, has been released in Sudan as a *Striga*-resistant variety named Mugawim Buda 2, and as IS 2391 and IS 3693 in Swaziland (Mengesha 1993). It has also been adopted in *Striga*-affected areas elsewhere. Applicability of a technology beyond its target environment is termed 'technology spillover'. Such spillovers may occur randomly or through planned intervention. Randomly occurring technology spillover depends on chance, while planned spillover depends on well informed and judicious intervention in research and development. Careful and systematic consideration of all critical factors (agroecological, biological, and institutional) should be followed by conscious efforts to realize any planned spillovers. The identification of potential spillovers, and the steps needed to realize these spillovers, can be fostered by creating a database containing all relevant information.

This paper discusses the importance of a sorghum database for enhancing technology spillover among CLAN member countries, and presents the types of data to be assembled, maintained, and distributed among research partners for this purpose.

Role of the Sorghum Database in Enhancing Spillovers

Resources for agricultural research are becoming increasingly scarce. Fund scarcity demands more efficient utilization of available resources and greater collaborative efforts among scientists in different institutes or countries to generate indirect benefits via technology spillovers. The extent of potential spillover of an agricultural technology depends on agroecological similarity (usually measured by rainfall, temperature, seasonal distribution of rainfall and temperature, and soil type and quality). Realization of

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potential spillovers, i.e., actual spillover, is influenced by such factors as historical and cultural links between countries, geographical proximity, institutional factors (e.g., research networks, quarantine laws, property rights), and the complexity of the problem (Byerlee 1997).

Exchange of information and technology and collaborative research efforts are vital for technology spillover. Several regional sorghum research networks operate — CLAN in Asia, the SADC/ICRISAT Sorghum and Millet Improvement Program (SMIP) in southern Africa, the West and Central Africa Sorghum Research Network (WCASRN), and the Comision Latinoamericana de Investigadores en Sorgo (CLAIS) in Latin America. These networks provide a forum for regular exchange of information and research products and for joint research planning. For example, collaboration under SMIP has led to the full integration of ICRISAT's program into national research and extension systems in southern Africa.

Research partnerships and channels for information exchange among Asian sorghum scientists are in place. Initially, these operated through the Cooperative Cereals Research Network (CCRN), which had a mandate extending beyond Asia. Partnerships for legumes research operated through the Asian Grain Legumes Network (AGLN), which was solely Asian. The Cereals and Legumes Asia Network (CLAN) was formed by merging AGLN and CCRN to establish a unified network for all ICRISAT mandate crops. It was envisioned that collaborative breeding research to develop cultivars adapted to local conditions, and exchange of germplasm and breeding populations with sources of resistance to major stress factors, would be major areas of collaboration among the network member countries (Byth 1993).

International nurseries and trials and germplasm exchange were helpful for sorghum crop improvement in the past. But this approach was not cost effective since the majority of the lines distributed were not useful to the recipient countries. Consequently the emphasis has changed to supplying specific, improved breeding material. Germplasm distribution has also shifted from unrestricted distribution to a system that is selective and responsive to requests from users. In addition, member countries can exchange materials (germplasm/varieties) bilaterally or multilaterally. Currently available technologies in the region can help improve productivity in other member countries, providing spillover benefits. For example, sorghum cultivars developed in India seem very promising for use in Thailand and Indonesia. In the same manner, improved cultivars released by different member countries may also be useful in other countries.

A major constraint to realizing technology spillovers among network member countries is the lack of information. Information gaps can be minimized by developing and maintaining a consistent system of data collection, processing, and dissemination. A database containing information on elite cultivars in the region would encourage targeted and efficient exchange of germplasm. The database would also help quantify the impact (both direct and spillover) of collaborative research, development, and diffusion by ICRISAT and the national programs. Development of a sorghum database is one of the proposed objectives of Asian sorghum researchers: "to develop efficient databases and sharing of information". The recommendations of the 1993 sorghum researchers meeting also included such a database as one of the objectives of CLAN (Gowda and Stenhouse 1993), but this has not yet been realized.

Minimum Data Requirement

Four types of data need to be maintained in the sorghum database. These are: recommended sorghum cultivars and their characteristics, status of sorghum cultivation, research capability, and economic factors affecting sorghum production.

Sorghum cultivars and their characteristics

The first requirement for the database is a complete list of all recommended sorghum cultivars in different countries and their characteristics. This should include information about origin of the cultivar, type of cultivar (i.e., variety or hybrid), pedigrees, the year of release, morphological characteristics (grain color, insect and disease resistance), ecological niches (humid, subhumid, moist semi-arid tropics, dry semi-arid tropics) for which they are released, commercial success (area cultivated), and the reasons for release (grain, forage, dual purpose, etc.). This information will help scientists understand what elite cultivars are available in different countries and where else they could be useful. Information about the performance of enhanced germplasm materials and their traits observed during the Advanced Line Adaptive Research Trials (ALART) in each country would also be useful. National breeding programs can utilize elite cultivars and advanced lines available in other countries and thereby increase their own research efficiency.

Status of sorghum cultivation

Information on the status of sorghum cultivation (area, production, yield) in different countries by environment and by cultivar will provide a clear understanding of the spread and popularity of different cultivars. Therefore, information on area under different cultivars (hybrids, improved varieties, local varieties) must be an integral part of the sorghum database. The composition of sorghum cultivars grown in farmers' fields changes over time. New cultivars often replace old ones for different reasons such as higher yield or resistance to biotic and abiotic stresses. Information on the spread of different cultivars and cultivars replaced by the new releases will help understand the comparative advantage of different cultivars at farm level. Information on yield gaps between farmers' fields and research stations, and the reasons for such yield gaps, will also be useful for this purpose.

Research capability and infrastructure

The level of research capacity by public and private research organizations is also important for technology spillover. Information about research capacity reflected through the number of scientists involved in sorghum improvement in public and private research organizations is important for the database. Information on subsequent efforts to promote and produce improved seed (number of seed companies operating in the country) will provide a clearer perspective of efforts on sorghum productivity enhancement in each country.

Economic factors

Time series information on economic factors affecting sorghum production (consumption, prices of inputs and outputs, credit availability, price support by the government, demand and supply elasticities) are important components of the database. If this information is compiled for different regions, provinces, and districts for each country, it can be analyzed to understand the spatial and temporal influence of these economic factors on sorghum production. This will help design appropriate policy packages to boost sorghum production.

Ongoing Efforts at ICRISAT

ICRISAT has already started assembling the information required to build a sorghum database. The Research Evaluation and Impact Assessment (REIA) compendium (Bantilan et al. 1998) contains a list of sorghum cultivars developed and released in different countries using ICRISAT-supplied material. Adoption data are collected through country-level studies conducted under the impact assessment project. Secondary data aggregated at the state and district level for area, production, yield, and adoption of high-yielding varieties are also included in the project database. CLAN has also collected some information. However, the data collected on released cultivars and their characteristics are incomplete; information gaps remain for certain variables. To fill these gaps in cultivar-related information, the spillover impacts study team has sent questionnaires to the different NARS. Eventually a comprehensive list of all released cultivars, along with their traits and area cultivated, will be compiled.

As part of the 'Spillover Impacts Study', the REIA project is analyzing FAO data on area, production, yield, and sorghum prices for all sorghum-producing countries for the period 1961-96. For India, the analysis will cover the period 1966-94, using district-level data on sorghum area, production, and yield, and monthly rainfall collected from the Directorate of Agriculture of various states. Similar data need to be compiled and computerized for all other member countries.

Once compiled, the data should be systematically documented and updated. Systematic development of a database requires:

- A data-file naming convention applicable to information from all countries
- A standardized file structure for each type of data, and data file linkages to eliminate duplication
- A file entry and retrieval system that facilitates retrieval and analysis.

Conclusions

Information is the key to planned development. And in order to enhance technology spillover among CLAN countries, it is vital to have fast, easy access to accurate information. Providing the right information to the right people at the right time will help maximize technology spillovers. A carefully documented sorghum database can serve as the information source for this purpose. Being an international institute, ICRISAT should take up leadership in assembling, maintaining, and disseminating such data to enhance both germplasm exchange and technology spillovers among CLAN countries.

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Country Reports

Sorghum in Australia

R G Henzell[1]

Introduction

Grain sorghum is grown on approximately 0.8 million ha in Australia to produce about 1.4 million tons per year. It is grown between latitudes 23° and 30° south in the states of Queensland and New South Wales, as a rainfed crop. As in many other countries, economic competition from such crops as cotton is forcing sorghum into areas that are even more water-deficient. Almost all the produce is used as feed grain in Australia, but some is exported to Japan. The entire crop is sown to hybrids, so there is a well-established seed industry. Currently there are five seed companies marketing grain sorghum in Australia.

Sorghum Research in Australia

In 1993 sorghum research in Australia was aggregated into a 'program' which is now called The Crop Improvement of Grain Sorghum in Australia'. The Grains Research and Development Corporation (GRDC) funds research based on proposals submitted by researchers with a clear focus on the researchable needs of clients (farmers, seed industry, etc.). The current program comprises eight sorghum projects, plus four sorghum-related projects. It is a multi-institutional program with a high level of collaboration and linkages between projects. The individual projects are briefly described below.

Core breeding. The overall aims of this project relate to the development of germplasm for use in other breeding programs: enhancing and broadening the genetic base of midge resistance and stay-green, and combining them. Other objectives (in addition to the usual disease resistances, maturity, height, head type, etc.) include:

- Incorporation of the waxy gene into the above gene pool
- Breeding dual-purpose hybrids with midge resistance, stay-green, low lignin, tan plant colour, and waxy endosperm
- Tolerance to Johnson grass mosaic virus
- Resistance to ergot via good pollen production under cool/cold conditions
- Improvement of yield per se using reciprocal recurrent selection.

Marker-assisted selection in sorghum.. This project aims to develop markers for the important traits segregating amongst some recombinant inbred lines from the cross

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QL39/QL41. A map has been produced with about 200 restriction fragment length polymorphism (RFLP) markers and a smaller number of microsatellites. Preliminary results indicate that markers for midge resistance and stay-green will be forthcoming. The important RFLP markers will be converted to polymerase chain reaction (PCR) markers before being used routinely for marker-assisted selection.

Analysis of sorghum pedigrees with molecular markers. This project aims to use molecular markers to determine the relationships amongst the materials in the Core Breeding Project. The results are particularly interesting and have been useful in corroborating some of the results from the Molecular Marker project.

Genetic potential to improve utilization of water and nitrogen resources in grain sorghum production. The three broad aims of the project are to:

- Quantify the extent of genetic variation for nitrogen-use efficiency and yield potential in different nitrogen x water production environments
- Characterize the physiological basis of genetic variation for the utilization of nitrogen and water in grain sorghum production
- Assess options for optimizing water- and nitrogen-use efficiency by crop management and genotype combinations for diverse environments.

Investigate new sources of midge resistance in grain sorghum. Midge-resistant hybrids currently grown in Australia possess only one mechanism of resistance. Other mechanisms have been reported for other germplasm. In the future it may be possible to transform sorghum to incorporate genes expressing midge resistance.

Management of *Helicoverpa armigera* on sorghum. Relationships between *Helicoverpa armigera* larval numbers and damage are being assessed on midge-resistant, open-panicled sorghum in order to develop economic thresholds for control. Extensive trials are being carried out to assess the use of a nuclear polyhedrosis virus to control *Helicoverpa* on sorghum.

Assessing G x E interactions to improve efficiency of sorghum breeding. The aims of this project, which was completed in Jun 1997, were to enhance the efficiency of yield testing and germplasm development by:

- Quantifying the magnitude and form of genotype by environment (G x E) interactions in target production environments
- Assessing the potential of utilizing genetic variation in various plant traits to improve productivity.

Physiological assessment of genetic variation in the stay-green trait. This project was designed to enhance the development of germplasm containing the stay-green gene by assessing the extent of genetic variation in this trait, understanding the physiological basis of such variation, determining the value of the trait in a wide range of target environments using simulation modelling, assessing the heritability of the trait and, if low, developing molecular markers for the trait.

Other Sorghum-Related Projects

Overcoming sorghum production constraints in rainfed environments in India and Australia. The aims of this project are to:

- Enhance genetic transformation techniques to help develop sorghum varieties with high and stable levels of resistance to sorghum shoot fly
- Develop improved testing methods for plant breeding through better analysis and design of multi-environment testing
- Develop improved crop models and climatic and soil databases to be able to simulate water and nitrogen effects on crop production and predict the consequences of management changes.

Improving transpiration efficiency in sorghum. The aims of this project are to:

- Provide a basis for introducing germplasm into the Core Breeding project by screening sorghum genotypes for variation in transpiration efficiency under water-limited conditions
- Improve the understanding of the physiological basis of genetic variation for transpiration efficiency to assist in the development of selection indices.

Transformation of grain sorghum. This work is aimed at developing protocols for sorghum transformation.

Development of management strategies for sorghum ergot. The aims of this project are to:

- Develop management strategies, including chemical, biological, and modelling, for sorghum ergot
- Develop efficacious and cost-effective fungicide application techniques
- Minimize harvesting problems due to ergot honeydew by modifying harvesting equipment
- Identify sorghum parents and genotypes with high pollen production and viability and with high stigma receptivity, especially under cool temperatures.

Sorghum Research and Development in China

Yang Zhen[1], Wang Liangqun[2], and Shi Yuxue[1]

Introduction

Early in this century, sorghum (known locally as *kaoliang)* covered about a fifth of the total cultivated area in China, and ranked third in importance behind rice and wheat. Sorghum is still one of the most important cereals in the semi-arid regions of north-eastern and north-western China, where natural calamities are fairly frequent. With rapid economic development in China, the role of sorghum has changed markedly during the past decades. Sorghum has become less important as a food and feed source, but is a very important raw material for the brewing industry. This shift is attributed to the improvement of agricultural production conditions, and changes in people's food preferences from sorghum to rice and wheat. In 1952, sorghum area was 9.4 million ha (6.6% of the national cropped area), while in 1996 it was only 1.2 million ha. However, yields have increased from 1.20 t ha^{-1} in 1952 to 4.01 t ha^{-1} in 1996.

Changes in Sorghum Production Systems

Area, production, and productivity. Sorghum has progressed from being a subsistence crop into a cash crop. It is estimated that 30% of total area sown is for forage production, 25% for grain for alcohol manufacture, 40% for food grain, and the remainder for fodder, building, or fencing materials. The cropped area, production, and productivity of sorghum in China are shown in Table 1. Liaoning, Shanxi, Jilin, Heilongiang, Hebei, and Sichuan are the major sorghum- growing provinces.

Table 1. Area, production, and productivity of sorghum in China, 1990-96.

Year	Area (million ha)	Production (million tons)	Yield (t ha^{-1})
1990	1.5	5.7	3.7
1991	1.4	4.9	3.6
1992	1.3	4.7	3.6
1993	1.4	5.7	4.2
1994	1.4	6.4	4.6
1995	1.2	4.9	3.9
1996	1.2	4.9	4.0

Source: Agriculture Yearbook of China (1996)

1. Sorghum Research Institute, Liaoning Academy of Agricultural Sciences, No. 84, Dongling Road, Shenyang 110161, Liaoning Province, China
2. Sorghum Institute, Shanxi Academy of Agricultural Sciences, Yuci City, Shanxi, China

Cropping systems and geographical distribution. Sorghum cultivation over the years has gradually moved from semi-humid regions with fertile soils to semi-arid regions with poor soil fertility. Thus, it has become a major crop in rainfed areas populated by ethnic minorities. Cropping systems have also changed; monocropping has given way to intercropping with potato or wheat and sequential planting after wheat.

Constraints to sorghum production. The key biotic and abiotic constraints to sorghum production in China are listed in Table 2. The major abiotic stresses are drought, poor soil fertility, and low temperature. The major biotic constraints are aphids, stem borer, and head smut.

Table 2. Biotic and abiotic constraints to sorghum production in China.

Constraint	Importance rating[1]	Yield loss (%)
Drought	1	10
Low temperature	3	5
Salinity	4	3
Soil nutrition/texture	2	8-10
Biotic stresses		
Aphids *(Melanaphis sacchari,* M. *sipha flava)*	1	10-15
Asia corn borer *(Ostrinia furnaculis)*	2	10
Armyworm (*Spodoptera* sp)	4	4
Head smut *(Sphacelotheca relianana)*	2	10
Charcoal rot/stalk rot	3	3
Anthracnose	3	5
New diseases		
Blotch *(Bipolaris sorghicola)*	4	3
Pokkah boeng (*Fusarium moniliforme)*	4	3
Acremonium wilt (*Acremonium strictum)*	4	3

1. On a 1-5 rating scale where 1 = very important, 5 = least important

Sorghum Research Focus

Institutional changes relating to sorghum research. The change in end-product needs has resulted in new plant type requirements for sorghum varieties or hybrids. In addition to high yield, emphasis is now placed on better resistance to drought, salinity, poor soils, diseases, and insect pests. The objective is thus to select varieties or hybrids to meet specific needs in food, feed, alcohol manufacture, and industrial products.

Improvement of production. A series of hybrids have been developed using traditional three-line hybrid technologies based on A., cytoplasm (Table 3). These efforts have contributed to progressive increases in productivity.

Table 3. Yields of hybrid sorghum in China.

Typical hybrid	Years	Yield ($t\ ha^{-1}$)	Pedigree	Institution[1]
Jinza No. 5	1970s	6.0-6.5	CK60A x Jin Liang No.5	SAAS
Liaoza No. 5	1980s	6.5-7.0	ATX622 x Jin Fu No.l	LAAS
Liaoza No. 4	1990s	>7.0	SPL 132 x Ai No.4	LAAS
Shenza No. 5	1990s	>7.0	ATX 622 x 0-30	SIAS
Liaoza No. 10	1996	>9.0	A 7050 x 9198	LAAS

1. SAAS = Shanxi Academy of Agricultural Sciences, Taiyuan; LAAS = Liaoning Academy of Agricultural Sciences, Shenyang; SIAS = Shenyang Research Institute of Agricultural Sciences, Shenyang

On-going research to increase productivity emphasises:

- Breeding for high yield using heterosis
- Breeding for multiple resistance to environmental stresses (a new breeding objective at most research institutions)
- Apomixis research to develop facultative apomictic lines for the development of varieties and hybrids
- Breeding for good quality for food, feed, alcohol (beverages), and forage
- Somaclonal variant screening and gene transfer techniques to improve the efficiency of breeding
- Recurrent selection to develop parental lines for the hybrid program.

Prospects for the Future

- Resolving the complex and sometimes negative relationships between yield, resistance, quality, and specific maturity requirements will be a major objective
- Collection, evaluation, and identification of sources of resistance in sorghum germplasm will be increased
- Selection for increased heterosis will be emphasized
- Diversifying male-steriles with Chinese cytoplasm resources will enable the full utilization of exotic restorer sources
- Sorghum production will be boosted by developing cultivars suitable for forage, feed, and food uses.

Suggestions for Future Cooperation

- Sorghum germplasm exchange to meet the needs of sorghum production and breeding in China and other countries
- Information exchange to aid sorghum scientists' access to current literature
- Strengthen cooperation among scientists working in different countries to exchange information and germplasm resources
- Enhance funds for cooperative research in key research areas such as development of male-sterile lines; resistance screening for leaf diseases, head smut, and aphids; and breeding for combined (multiple) resistance.

Sorghum Improvement in India

B S Rana and S L Kaul[1]

Introduction

Sorghum is currently grown on over 12 million ha in India. The grain is used for food and the stover for animal feed. In addition, there is an undocumented area of 2.5-3.0 million ha of sorghum grown for green forage.

Since 1970, total sorghum area has declined by 36% but yields have increased substantially, with the result that overall productivity has remained more or less the same. The decrease in area and increase in productivity have been much more marked in rainy-season sorghum. Postrainy-season sorghum has declined much less in area but has also shown smaller improvements in yield. Approximately 6 million ha each of rainy-season and postrainy-season sorghum are now grown. Grain yields are approximately 1.0 t ha^{-1} in the rainy-season crop and 0.65 t ha^{-1} in the postrainy season.

Research Areas and Achievements

Rainy-season sorghum. The target for rainy-season sorghum has been to develop dual-purpose hybrids and varieties and short-duration hybrids for moisture stress conditions. Recent releases include CSH 13, a dual-purpose hybrid that yields 14.5 t ha^{-1} of dry fodder and 4.0 t ha^{-1} of grain, and CSV 15, a dual-purpose variety that yields 12.2 t ha^{-1} of dry fodder and 3.6 t ha^{-1} of grain. CSH 14 is a recently released short-duration hybrid (approximately 100 days to maturity). CSH 16 and MLSH 296 are very recent releases that give 9% higher yields than CSH 9, which remains the most widely cultivated hybrid.

Postrainy-season sorghum. Dual-purpose cultivars with resistance to shoot fly, charcoal rot, terminal drought, and low temperatures at flowering are required for the postrainy season. CSH 13R has demonstrated a 48% superiority in grain yield over the popular local variety M 35-1 but requires further improvement in shoot fly resistance and grain size. CSH 15R combines productivity with other desired features for adaptation and consumer acceptance. A number of promising hybrids and varieties with moderate levels of resistance to shoot fly have been identified. Poor seed set in hybrids due to low night temperatures has prevented their yield advantage from being realized.

Sweet-stalked sorghum. SSV 84 is the standard sweet-stalked sorghum variety and can yield 3.0 t ha^{-1} of jaggery (raw sugar). More recently identified varieties, such as AKSS 15 and AKSS 16, yield 35-40 t ha^{-1} of green stalks and 15 000 to 19 000 liters ha^{-1} of juice, capable of yielding 1550-2100 liters of ethanol.

1. National Research Centre for Sorghum, Rajendranagar, Hyderabad 500 030, Andhra Pradesh, India

Multicut forage sorghum hybrids. Sorghum x Sudangrass hybrids with high yields, good quality forage, and the ability to regenerate after cutting are important for green forage production. A number of hybrids have been produced and are being marketed by the private sector, which has dominated this area of research.

Issues for Sorghum Production in India

Poor competitiveness of rainy-season sorghum. Grain yields have increased more than three-fold in the main sorghum-growing areas. In spite of this, sorghum cultivation has declined because it is less profitable than other oilseed and pulse crops and cotton, which compete for the same agroecological areas. These crops have replaced sorghum to a variable extent in different states. Higher-yielding hybrids with increased grain mold resistance and lower production costs, and increased demand for sorghum for alternative uses as feed and raw material for industrial processing, could remedy this problem.

Delayed onset of the monsoon. When the onset of the monsoon is delayed beyond a certain date, farmers will not sow sorghum. This is largely due to severe shoot fly attack in late and staggered sowings. Climatic change appears to be causing increased frequency of late onset of the monsoon, leading to decreases in area and production. The answer to this problem appears to lie in developing short-duration cultivars with shoot fly resistance.

New cropping systems. Sorghum is being replaced by other crops, as traditional cropping systems have been abandoned in favor of new, more profitable ones. Sorghum cultivars that fit into the new cropping systems are required. These may involve shorter-duration cultivars to fit into new crop sequences in intensified systems, or changed morphology to fit into intercropping systems with new crops.

Fodder and feed requirements. The importance of stover as animal feed is one of the main reasons why farmers continue to grow sorghum. High fodder yield is required in both rainy-season and postrainy-season cultivars. Similarly, feed grain demand is increasing in Asia, and India may have a competitive edge in supplying this market. The possibilities of grain export need to be explored as well as novel cropping options (e.g., sorghum production in rice fallows) to produce grain for this use.

Postrainy-season production constraints. Little impact has been made on postrainy-season sorghum production. To change this, the specific constraints that affect the crop need to be addressed. Shoot fly resistance, charcoal rot resistance, and tolerance to low temperatures at flowering need to be improved. The direct effects of receding soil moisture and their effects on nutrient uptake need to be mitigated by introducing new technologies, including supplementary irrigation.

Major Future Goals

- Increase the productivity of postrainy-season hybrids under receding moisture and irrigated conditions

- Break the yield plateau of rainy-season hybrids
- Breed new, genetically diverse, cytoplasmic male-sterile lines with bold grain and resistance to grain molds and shoot fly
- Breed sorghum x Sudangrass hybrids for multicut forage production
- Broaden the genetic base of existing breeding programs
- Improve the profitability of sorghum by reducing production costs, reducing crop losses to grain molds, developing new intercropping and sequential cropping systems for sorghum, and promoting demand for alternative uses
- Improve water- and nutrient-use efficiencies in rainfed and irrigated postrainy-season production systems
- Identify durable sources of resistance to biotic and abiotic stresses, breed improved sources, and deploy them through cost-effective integrated pest management strategies.

Opportunities for Collaboration

There is potential for collaboration in any of the above areas. In addition, collaboration would also be possible in several new areas, involving other CLAN countries and external organizations. These areas include:

- Genetic transformation for resistance to shoot fly and stem borer
- Development of improved management strategies through the application of crop models
- Technical, policy, economic, and social factors affecting sorghum utilization
- Molecular fingerprinting of varieties and germplasm
- Wide hybridization for introgressing shoot fly resistance from wild relatives.

Sorghum Research and Development for Dryland Areas in Indonesia

D Baco, M Mejaya, and S Singgih[1]

Introduction

In Indonesia, sorghum is grown for both human food and animal feed. It is a minor crop among cereals, grown in marginal areas with relatively low soil moisture content. Consequently, sorghum research has traditionally been of low priority. However, sorghum is tolerant of drought and waterlogging and is therefore a potential crop for the eastern parts of Indonesia.

Production, Area, and Productivity

The main production areas are East and Central Java, South Sulawesi, East and West Nusa Tenggara, and East Timor in agroclimatic zones C2-C3 (5-6 consecutive wet months and 2-4 to 5-6 consecutive dry months) and D2-D3 (3-4 consecutive wet months and 2-4 to 5-6 consecutive dry months). As it is a minor food crop, statistical data on area, production, productivity, demand, export, and import are unavailable. A study conducted by the Department of Agriculture during 1987/88 showed that total sorghum harvested area was around 18 600 ha, production 26 500 tons, and productivity 1.43 t ha^{-1}. For the period 1989-96, data are available only for East Nusa Tenggara and Central Java provinces. In East Nusa Tenggara, the annual area sown to sorghum increased from less than 310 ha in 1987/88 to more than 10 000 ha during 1989-92, and then declined to less than 8000 ha in 1996. The shift to other food crops (often maize) in Java is usually due to reasons of price and profitability.

Production Constraints

As a minor food crop, sorghum receives less attention than staple food crops such as rice, maize, and soybean. The major constraints to increasing sorghum production are as follows:

- Sorghum is usually grown in rainfed marginal lands and remote areas, mostly mix-cropped with other food crops
- Most traditional farmers grow sorghum under low inputs: poor quality seed, low-yielding local varieties, low doses of fertilizer, no protection against pests and diseases, improper plant densities, and improper post-harvest handling and processing

1. Research Institute for Maize and Other Cereals, Jalang Ratulangi, Maros 90514, South Sulawesi, Indonesia

- The low market price for sorghum does not offer farmers an incentive to increase production.

Collaborative Research

Cooperation in sorghum research between ICRISAT and the Research Institute for Maize and Other Cereals (RIMOC) was established with the objective of assisting Indonesia in germplasm exchange, training, technical advice, and publications. Collaborative research has also been conducted with the Indonesian Sugar Research Institute on sweet-stalk sorghum since 1992. ICRISAT, through CLAN, has provided a range of genetic materials for evaluation and use in the breeding program. Research activities include evaluation of sorghum lines for drought tolerance, evaluation of hybrids and varieties for yield, evaluation of sweet-stalk genotypes, and evaluation of genotypes for disease/insect resistance. Promising genotypes have been identified and tested in multilocational trials preparatory to release, or used as donor parents for specific traits to improve local varieties.

Future Plans

Rapid progress can be made in technology generation, adaptation, and adoption by pooling resources and expertise. This will facilitate the exchange of improved genetic material and germplasm, and cooperative research and development on sorghum production and utilization.

Sorghum Research in Iran

A F Ajirlou[1]

Introduction

Iran lies between 25-40° N latitude and 44-64° E longitude. The country has a wide range of climatic conditions, from cold, arid, and moderate climate in the north and northwest, to hot and dry in the central regions, and hot and tropical in the south. About 10 million ha of cultivated area in Iran are occupied by cereal crops (wheat, barley, rice, maize, and sorghum).

Sorghum in Iran

References in Persian literature indicate that sorghum was cultivated in Iran in ancient times. Landraces are found mostly in central and southern Iran. The early geographical distribution of sorghum in Iran suggests that the crop was introduced into many countries via the ancient silk route from Asia across Iran.

Sorghum cultivation in Iran has decreased over the past 50 years, with sorghum being replaced by maize, but has increased in recent years. Only limited information is available on cultivation practices, varieties, date of sowing, irrigation, fertilizer dosages, etc. Sorghum area has increased from 10 000 ha in 1993 to about 30 000 ha in 1997 (Table 1). Of this, 27 000 ha is under forage sorghum. Sorghum research in Iran began 12 years ago and some landraces were collected. Some varieties and germplasm received from ICRISAT were used to develop higher-yielding pure lines.

Sorghum is cultivated in Iran for several uses. These are, in decreasing order of importance: forage, feed grain especially for poultry; and sweet sorghum for liquid sugar and feed.

Forage sorghum. Forage is the most important use of sorghum in Iran. Farmers are interested in multicut forage varieties, and harvest 2-4 cuts per year under full irrigation. Besides local varieties, forage sorghum hybrid parents introduced from Australia are used to produce hybrid seed in Iran. Improved pure lines and varieties, now in the final stages of testing, will soon be released to farmers for cultivation.

Grain sorghum. Grain sorghum is used as a food (especially for confectionery), poultry feed (as a replacement for maize), and for the industrial production, of starch and glucose, where it can replace wheat and maize. Currently a limited area is sown to grain sorghum, because the local varieties are tall and unsuitable for mechanized harvesting. Bird damage prevents successful grain production in most areas, especially of white-grained cultivars. However, improved pure lines and varieties are being evaluated in some parts of Iran. The three best are Payam, Kimiya, and Sepeedeh, with an average grain yield of 6-10 t ha^{-1} under full irrigation and when protected from bird damage.

1. Seed and Plant Improvement Institute, Mardabad Avenue, Karaj 31585, Iran

Table 1. Cropped area, production, and productivity of green fodder[1] sorghum in Iran, 1994-97.

Year	Area ('000 ha)	Production ('000 t)	Yield (t ha^{-1})
1994	14	1050	75
1995	19	1501	79
1996	23	1932	84
1997	27	2349	87

1. Approximately 20-25% is for dry fodder

Production Constraints

An important constraint to the cultivation of forage sorghum is the lack of appropriate machinery for harvesting and chopping.

Abiotic stresses. Most of the sorghum grown in late spring and summer is irrigated wherever water is available, and hence drought (though it occurs in several areas) is not a major problem. Salinity is an important constraint, and is being addressed by using salt-tolerant varieties.

Biotic stresses. Bird damage is the most important constraint to both seed and grain production. Other stresses are not very important.

Current Research Thrusts

Sorghum research is conducted at 18 stations of the Seed and Plant Improvement Institute. Major areas of research include:

- Developing new lines and varieties adapted to Iranian conditions
- Breeding research on combining ability to produce hybrids
- Evaluation of varieties and hybrids (forage and grain) for suitability in different areas
- Evaluation of varieties and hybrids for salinity tolerance
- Agronomy research to determine optimum cultural and management practices.

Future Plans

- Screening of local and exotic germplasm, and segregating generations, for tolerance to salinity and drought
- Mechanization of sorghum production with regard to tillage operations, sowing, harvesting, threshing, and chopping
- Expansion of grain sorghum cultivation to other areas in the country by developing high-yielding varieties with bird resistance.

Sorghum Research and Development in Myanmar

Khin Mar Yee[1]

Introduction

In Myanmar, sorghum covers the second largest area (after rice) among cereals. Area and production of grain sorghum in Myanmar for the last 10 years are presented in Table 1. The main sorghum-producing areas are Magway, Mandalay, and Sagaing divisions in the semi-arid tropics, followed by Chin and Kayah states in the sub-tropics. Sorghum is used mainly as food (a small percentage of grain production in rice-deficit areas during food shortages), feed, and fodder. Sorghum area has increased during the last decade. Total production increased during the 1990s primarily due to increases in area. Productivity was highest during 1986/87 and 1987/88 due to the impact of production programs launched by the government. Dual-purpose sorghum is usually sown as second crop, following early sesame or legumes such as mungbean, in the mid-monsoon season. For green fodder it is normally sown with the onset of the monsoon, as a sole crop. Dual-purpose sorghum is either sole-cropped or intercropped with pigeonpea, mungbean, groundnut, or sunflower. Sorghum is grown only under rainfed conditions in Myanmar.

Production Constraints

Sorghum production in Myanmar is limited by a number of factors. These include: biotic stresses (shoot fly, stem borer, anthracnose, ergot, grain mold, birds, *Striga),* abiotic stresses (poor soil fertility, erratic rainfall, moisture stress), socio-economic factors (slow adoption of improved varieties, high price of inorganic fertilizer and pesticides due to limited supplies, low price of sorghum grain, lack of financial support and marketing infrastructure), and institutional bottlenecks (lack of attention by policy makers, nonavailability of quality seed, lack of trained personnel).

Sorghum Research in Myanmar: Past and Present

Sorghum research was first initiated at the Central Agricultural Research Institute (CARI), Yezin, in 1975. During its early stages, the program emphasized the development of multi-stress tolerant varieties and low-input technologies. From 1975 through 1980 many introductions were made from the Philippines and from Mexico. Out of these introductions, 14 high-yielding varieties (13 grain types and one dual-purpose type) were identified and released as commercial varieties. They are of different

1. Dryzone Agricultural Research Farm, Nyaung Oo, Myanmar

Table 1. Sorghum area and production in Myanmar, 1986-96.

Year	Area ('000 ha)	Production ('000 tons)	Yield (t ha^{-1})
1986/87	220.4	252.1	1.14
1987/88	192.1	200.9	1.05
1988/89	177.4	128.6	0.73
1989/90	187.4	124.2	0.66
1990/91	180.2	135.9	0.75
1991/92	190.6	128.4	0.67
1992/93	209.6	141.7	0.68
1993/94	212.8	147.3	0.69
1994/95	215.6	130.6	0.61
1995/96	230.0	151.0	0.66

maturity durations with seed color ranging from brown to dark red. In some areas, the new varieties rapidly replaced the landraces. However, farmers realized that these brown/red grain varieties had low food and feed grain quality, and so the area under these varieties declined. Therefore, the sorghum improvement program after 1980 emphasized the development of white-grain varieties.

From 1980 onwards, new introductions were made from ICRISAT, and tested extensively at CARI, Yezin and its satellite stations. Out of these, four white-grain varieties (M 90906, M 36248, M 36335, and M 36172) were released in 1984/85 as commercial varieties. Three more high-yielding varieties introduced from ICRISAT (ICSV 804, ICSV 735, and ICSV 758) were released as Yezin White Grain 5, 6 and 7, respectively, in 1991 and 1992. These released varieties generally mature earlier than existing local varieties and are prone to grain mold and bird damage. Moreover, the fodder storage quality is poor compared to that of landraces. The new varieties occupy around 10% of the country's total sorghum area.

Therefore, the emphasis in sorghum improvement is now being placed on the development of high-yielding, dual-purpose varieties with acceptable food and feed quality, good fodder storage quality, and resistance to pests (shoot fly and stem borer), diseases (grain mold and anthracnose), and *Striga.*

Several promising cultivars have been identified as a result of collaboration with CLAN/ICRISAT, and these are being tested multilocationally in advanced yield trials. Five promising lines were selected for seed increase to conduct on-farm demonstration trials.

Future Collaborative Activities

The ongoing collaborative activities with CLAN/ICRISAT have been very beneficial to the national program. The following future collaborative programs will further strengthen the national research program in Myanmar:

- ICRISAT sorghum scientists should visit the country at least once during the growing season to advise the national research program

- Technical assistance from ICRISAT is needed to collect and characterize the diverse sorghum germplasm in Myanmar
- Short-term training courses should be conducted, either in-country or at ICRISAT.

Status of Sorghum Production and Research in Pakistan

A Shakoor[1]

Introduction

Sorghum is an important grain and forage crop in Pakistan. About 90% of grain production is consumed on-farm as food and seed. Demand for grain for poultry feed has increased in recent years. Sorghum stover is used as dry fodder, particularly during the winter months. Sorghum is also grown for green fodder in irrigated areas near towns. The annual average area under sorghum in Pakistan from 1990 to 1995 was approximately 400 000 ha (Table 1).

However, it is difficult to assess the area and production of sorghum accurately as much of the crop is grown for forage and is harvested before grain formation. It is estimated that half the national sorghum area is rainfed and the other half irrigated; and that at least one quarter of the rainfed and half the irrigated crop is grown exclusively for forage. Total sorghum grain production averaged 235 000 tons per annum during 1990-95. This represents a reduction of approximately 10% since 1975-80, largely due to a decrease in area. Yield levels have remained more or less static at 580 kg ha^{-1} for many years (Table 1).

Sorghum Research and Development

Sorghum improvement was initiated in Pakistan in the late 1960s. Maize and Millet Research Institutes were established at Yousufwala (Punjab) and Pirsabak (North West Frontier Province, NWFP) in 1970/71, and a coordinated national program on maize, sorghum, and millet was established in 1975. This was subsequently split into separate programs for maize, and sorghum and millets. The National Cooperative Research Program on Sorghum and Millets was initiated in Mar 1987. Five research centers participate:

- Maize and Millet Research Institute, Yousufwala, Punjab
- Agricultural Research Station, D I Khan, NWFP
- Agricultural Research Station, Dadu, Sindh
- Agricultural Research Institute, Sariab-Quetta, Balochistan
- National Agricultural Research Centre, Islamabad, Punjab.

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Table 1. Five-year averages of sorghum area, production, and grain yield in different provinces of Pakistan, 1975-95.

Period	Punjab	Sindh	North West Frontier Province	Balochistan	Total
		Area ('000 ha)			
1975-80	218.4	139.1	27.6	81.8	466.9
1980-85	215.8	100.7	22.2	53.8	392.3
1985-90	224.9	103.0	21.9	42.8	392.5
1990-95	236.2	100.1	18.7	46.1	401.1
		Production ('000 t)			
1975-80	118.4	93.2	13.4	40.6	265.6
1980-85	118.6	62.9	11.1	33.2	225.8
1985-90	121.5	60.9	13.7	32.9	229.0
1990-95	128.8	56.7	13.2	36.8	235.5
		Yield (kg ha^{-1})			
1975-80	542	670	482	496	569
1980-85	544	400	438	500	486
1985-90	540	592	624	769	583
1990-95	545	566	706	798	587

Source: Agricultural Statistics of Pakistan, 1995/96

High-yielding exotic varieties have been identified and released but have not spread among farmers. The shortcomings of this material include poor grain quality, low fodder yield, late maturity, and poor germination and establishment under low-moisture conditions. Other factors contributing to this lack of spread include limited testing and demonstration on farmers' fields and the absence of efficient seed multiplication and distribution systems.

Farmers currently grow mainly landraces. The main varieties in Sindh are Sarokartuho, Red Janpuri, Depar, and Baghdar. In Balochistan, Baghdar, Bhoori, Bhawalpuri, Mithri, and Janpuri are preferred. In Punjab, Pak-SS-II, D.G. Pearl, NES-1747, PU-7, BR-319, and Jowar-86 are grown. In NWFP, DS-75 and Giza-2 are cultivated.

Production Constraints

Several factors are responsible for low productivity of sorghum in Pakistan:

- The crop is grown mainly in marginal areas, under drought stress
- Landraces are widely cultivated for both grain and stover, but have not been improved for either purpose
- Poor plant stands due to inadequate land preparation, inefficient sowing methods, poor quality seed, and drought stress and soil crusting during emergence
- Weeds, particularly in rainfed areas where rains during Jul and Aug may prevent timely weeding
- Insect pests and diseases.

Achievements of Sorghum Research in Pakistan

- Two varieties, PARC-SS-1 (ICSV 107) and PARC-SS-2 (IRAT 204), that yield approximately four times more grain than local cultivars (2.0-2.5 t ha^{-1} versus 0.5-0.6 t ha^{-1}) have been identified and over 3 t seed has been produced for distribution to farmers
- ICSV 745, ICSV 843, ICSV 680, CSV 13, IS 18531, and IS 22129 were found resistant to shoot fly and stem borer. ICSV 197 was found resistant to midge
- Sorghum hybrid PARC-SH-1 (CSH 6 from India) has been found to yield 3-4 t ha^{-1} and has been multiplied from its parents, 2219A and CS 3541
- Locally constituted hybrids ICSA 5 x ICSR 6, ICSA 4 x ICSR 10, and ICSA 3 x ICSR 7 have been shown to yield 5.0-5.8 t ha^{-1} of grain
- Improved agronomic management practices have been demonstrated in farmers' fields, and recommended for wider use.

Future Thrusts

- Increased emphasis on sorghum improvement for rainfed areas
- Farm-level surveys in the main sorghum-growing areas to clearly understand production constraints
- Collection, characterization, and conservation of local germplasm
- Reduced emphasis on testing introduced lines and greater emphasis on breeding short-duration, dual-purpose varieties and hybrids
- Continued research on management practices, particularly plant population, balanced fertilizer application, weed control, and mechanization for rainfed and irrigated conditions
- Commitment to on-farm generation, testing, and demonstration of improved sorghum production technologies.

Expectations from CLAN

Pakistan can contribute to CLAN through mutual exchange of germplasm, information, and joint research results, particularly in the areas of drought and heat stress, and disease and insect tolerance.

Strong linkages with CLAN would benefit Pakistan by providing:

- Elite sorghum germplasm for grain and fodder
- Screening techniques for drought, high temperature, shoot fly, and stem borer resistance
- Technical assistance through cooperative research projects
- Staff training and access to current research literature and methods.

Sorghum Research and Development in Thailand

N Iamsupasit[1], S Juttupornpong[1], K Lertprasertrat[1], T Pothisoong[2], and P Jaisil[3]

Introduction

Sorghum has been grown in Thailand for several decades and is recognized as a major cereal crop after rice and maize. This report gives a brief account of sorghum production systems in Thailand, current sorghum research activities, previous collaborative activities with ICRISAT, and future research needs.

Area and Production

The major sorghum-growing areas are in the Central and Northern provinces. The area has declined from 310 000 ha in 1985 to 129 000 ha in 1996, due to lack of export demand and competition from other field crops such as sunflower and maize. Even though grain cannot be exported, there is domestic demand for grain as animal feed. However, sorghum grain has to compete with maize, and is used as a substitute when maize production is insufficient. Since maize production does not meet domestic demand, there is considerable potential for increasing the country's sorghum area. Productivity has increased from 1.01 t ha^{-1} in 1980 to 1.40 t ha^{-1} in 1996. This increase is partly due to the adoption of high-yielding improved cultivars.

Cropping Systems and Geographical Distribution

The recommended sowing time for sorghum is from Aug to early Sep. However, early rainy season sowing (May-Jun) is practised in a few areas. In animal-based farming, dual-purpose sorghum is sown at the beginning of the rainy season. The main crop is harvested for fodder and the ratoon crop left for grain.

Importance of specific constraints. Grain yield on farmers' fields is low because of low- yielding varieties, inappropriate cultural practices, diseases (grain molds and ergot), insect damage (shoot fly and stem borer), low and erratic distribution of rainfall, and poor returns compared to other crops (lamsupasit 1993).

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3. Faculty of Agriculture, Khon Kaen University, Maung, Khon Kaen 40000, Thailand

Major Research Results

New improved varieties. The Department of Agriculture releases mainly pure-line varieties whereas Kasetsart University releases both pure-line and hybrid varieties (Table 1). Among the private seed companies, Pacific Seeds is active in Thailand and promotes mainly red grain hybrids.

Table 1. Sorghum varieties released and recommended in Thailand.

Variety	Parents	Type of variety	Grain color	Purpose
U-Thong 1	Ce 151.262$A_1P_1A_1$	Pure line	Light yellow	Grain
Suphan Buri 60	U-Thong 1 x SW 240	Pure line	Red	Grain
Suphan Buri 1	M 91019x WAE	Pure line	Red	Dual
KU 9501	KU 9410A x KU 804	Hybrid	Chalky white	Grain
KU 9502	KU 9402A x KU 630	Hybrid	Red	Grain

Alternative uses. The development and transfer of techniques to promote alternative uses of sorghum have been highly successful. For example, sorghum spikes/spikelets are used for ornamental purposes and fresh stalks to supplement pineapple bark to feed milch cows. Khon Kaen University is also working on the feasibility of producing ethanol from sweet sorghums.

Changes in Research Priorities

Research priority in sorghum remains unchanged (priority 2). Breeding for high-yielding varieties, both grain and dual purpose, is still the priority, followed by resistance to diseases and insects and tolerance to environmental stress.

Conclusions

Sorghum is a major cereal crop in Thailand. Moisture stress, shoot fly, and grain molds are the major yield-reducing constraints. Alternative uses of sorghum are also being studied. The main activity involving CLAN/ICRISAT is the exchange of germplasm and some promising advanced breeding lines, and these are now being tested in the national sorghum breeding program. We need to improve collaboration in the areas of human resource development and training. There is also a need to increase collaboration among CLAN member countries.

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Summary of Discussions and Recommendations

Summary of Discussions and Recommendations

Potential research areas were first listed, and then discussed in terms of possible activities that could be developed for collaboration. Potential research partners were identified, and modalities were discussed. On the basis of these discussions, decisions were made to include or exclude potential research areas for further development and implementation (Table 1). The discussions are summarized below.

Drought. All participants expressed interest in drought research, but the type of drought important for specific countries varied. The possible use of marker-assisted selection to backcross stay-green into adapted materials from national programs was raised. All countries expressed interest in participating in the program. Dr S L Kaul of the National Research Centre for Sorghum (NRCS, India) was nominated to coordinate this project with assistance from Drs V Mahalakshmi, N Seetharama (ICRISAT), and R G Henzell (Australia). Dr Mahalakshmi will make the backcrosses, Dr Seetharama will conduct the molecular work, Dr Henzell will assist in obtaining markers from the Queensland Department of Primary Agriculture and CSIRO, and Dr Kaul will coordinate the project. Together, these scientists will develop a work plan to be funded by an ongoing ICRISAT activity in the same area. Each participating country will nominate 2 or 3 released varieties which will be used in a marker-assisted backcrossing program to incorporate the stay-green trait. Training of key NARS scientists in marker-assisted selection is an important component of this project, and has excellent prospects for external funding.

Shoot pests. The stem borer, shoot fly, armyworm, and aphids were considered together as shoot pests. These remain high-priority constraints for most programs and are being addressed by them and by ICRISAT The resistance sources available at ICRISAT can be made available to interested NARS on request. Information on screening techniques is also available from ICRISAT

Feed grain quality. The use of sorghum as feed grain is becoming increasingly important in all CLAN countries. This raises the issue of feed grain quality. Apart from grain mold resistance, there are no clear directions or simple screening techniques for evaluating feed grain quality. Therefore, the opportunity to address this issue is not evident at present. Thus, no activity was proposed, apart from breeding for grain mold resistance.

Male sterility. Interest in developing alternative cytoplasmic male-sterility systems was expressed by China and India. In particular, A_2 cytoplasm was considered a high priority. The two important aspects are breeding improved male-sterile lines and restorers (especially for A_2, and inheritance of restoration in both A_1 and A_2 cytoplasms using molecular markers. Both these areas are of global importance. Since China has already made progress in using A_2 cytoplasm, it was nominated to take the lead in this activity. China, India (NRCS), and ICRISAT will develop a joint project proposal for submission to donors, seeking funding for a collaborative program by the three partners. CLAN will try to support project development.

Germplasm exchange. This has been the backbone of all collaborative activities and was considered important for the future as well, by all the national programs.

- **Exchange of released grain sorghum varieties.** To enhance collaboration among the member countries and promote the exchange of elite materials, it was decided that each country should contribute released cultivars for a nursery that will be distributed within the region. Due to the difficulty of assembling and multiplying seed for distribution, it was decided that only the released cultivars from India would be distributed in 1998. The issue of inclusion of hybrids was discussed; several countries (Thailand, Myanmar, Iran, Australia, Indonesia) expressed interest only in open-pollinated varieties. NRCS accepted responsibility for coordination and seed increase with assistance from ICRISAT for phytosanitary clearance and seed despatch.
- **Exchange of released forage sorghum varieties.** A similar activity to exchange forage sorghums within the region was proposed. Dr G P Lodhi agreed to coordinate this activity with assistance from ICRISAT for phytosanitary clearance and seed despatch.
- **Trait-based nurseries.** In the past ICRISAT has distributed a number of trait-based nurseries (e.g., for bold grain, early maturity, pest and disease resistance). These nurseries will be continued on request. This will continue to be part of ICRISAT's ongoing core technology exchange activity.
- **Database.** A database of information on elite cultivars in the region was proposed as a means to encourage targeted and efficient exchange of germplasm. ICRISAT accepted responsibility for preparing, maintaining, and making available such a database.

Forage-related traits. Several traits important for forage sorghums were discussed, and it was decided to place emphasis on diversifying Sudangrass restorers with resistance to leaf diseases and shoot pests. It was decided to develop a project on the latter for submission to a funding agency. Dr G P Lodhi will take the lead in this project, and NRCS and ICRISAT will facilitate the development of the project proposal.

Grain mold. A program to breed red-grained hybrids with resistance to grain molds was proposed. The inclusion of white-grained hybrids was suggested. However, white-grained hybrids that are likely to have mold resistance are not available. Only Thailand expressed interest in red-grained material and hence it was decided that this activity could be covered under bilateral germplasm exchange between ICRISAT and Thailand.

Soil salinity. This was proposed by Iran as a major problem. No other programs gave it priority.

Birds. Birds were considered a widespread problem. No obvious solutions suggested themselves.

Table 1. Agreed research areas for CLAN-assisted sorghum research, Suphan Buri, 20 Nov 1997.

Research area	Leader(s)	Funding	Responsibility for project development
1. Terminal drought resistance; marker-assisted backcrossing of stay-green into local material; both grain and forage sorghums	S L Kaul (NRCS, India)	ICRISAT (existing activity)	V Mahalakshmi, N Seetharama, J W Stenhouse (ICRISAT)
2. Germplasm exchange: (i) Released cultivars from national programs (ii) Forage sorghum (iii) Trait-based nurseries on request (iv) Database	(i), (iii): B S Rana, (ii): G P Lodhi, J W Stenhouse (iv): J W Stenhouse	ICRISAT (existing activity)	Not required
3. Male sterility systems (China). Genetics of restoration particularly in A_1 and A_2 cytoplasms (ICRISAT/India)	W Liangqun, Y Zhen (China) B V S Reddy (ICRISAT)	Project to be developed	Joint (ICRISAT/India/China)
4. Genetic enhancement of Sudangrass hybrids, especially R-lines	G P Lodhi	Project to be developed	Joint (India/ICRISAT)
5. Training and exchange visits	B S Rana, J W Stenhouse	Proposal to be prepared for funding	Joint (India/ICRISAT)

Dual-purpose sorghum, stover storage quality. Myanmar and Indonesia expressed interest in dual-purpose sorghum and good stover storage quality (Myanmar). This could be covered under germplasm exchange.

Training and exchange visits. Several participants emphasized the need for exchange visits to see each others' programs as a means to enhance collaboration and germplasm exchange; and to provide opportunities for targeted training in specialized research areas. No specific program **was** proposed but ICRISAT and CLAN agreed to consider this need when formulating their budgets. It was also suggested that other sources of funds available to NARS could be used for this purpose. It was proposed that the training and consultancy needs of the sorghum research group be consolidated into a proposal and funding sought.

Grain yield, bold grain. These were considered to be the highest priority by all national breeding programs.

Weeds. Management techniques are already available. The problem can be addressed through information exchange. The location-specific nature of this activity also makes it appropriate that it is addressed within national programs.

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About ICRISAT

The semi-arid tropics (SAT) encompasses parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, finger millet, chickpea, pigeonpea, and groundnut; these six crops are vital to life for the ever-increasing populations of the semi-arid tropics. ICRISAT's mission is to conduct research which can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services, and publishing.

ICRISAT was established in 1972. It is one of 16 nonprofit, research and training centers funded through the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is an informal association of approximately 50 public and private sector donors; it is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the World Bank.

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